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THERMAL EVALUATION OF A POLYVINYLCHLORIDE EXPOSURE SUIT (EMPRESS) AND COMPARISON WITH PRESENT SUBMARINE DECK EXPOSURE SUIT

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF022.03.03-9025.29

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SUBMARINE MEDICAL RESEARCH LABORATORY
U. S. NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 527

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SUMMARY PAGE

PROBLEM

To determine the survival time and the general performance of the "Empress" polyvinylchloride exposure suit (PVCES), and to compare its performance with that of the present submarine deck exposure suit (SDES). The study was conducted by investigators from the Submarine Medical Center, New London, Connecticut, using facilities of the U.S.N. Aerospace Crew Equipment Department, NADC, Philadelphia, Pa.

FINDINGS

The "Empress" (PVCES) did provide reasonable survival time at the extreme environmental condition (44°F water, 32°F air, 20 MPH wind) specifically desired. Increased exposure protection was provided by the PVCES versus the SDES. The inherent buoyancy offered by the PVCES contributed an additional positive factor. The mobility and rapid donning qualities inherent in this suit are points in its favor. The suit is durable and possibly only one size would be necessary to fit most of the crew. The exposure times indicate that a man or group of men could survive long enough for rescue from a "man overboard" situation.

APPLICATION

A submarine deck exposure suit of this type should be further developed and made available to the U. S. Submarine Force as soon as possible. The present submarine deck exposure suit is unsatisfactory and potentially hazardous in the opinion of the investigators.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Work Unit MF022.03.03-9025—Assessment of Factors Related to Submarine Habitability, Escape and Rescue and New Equipment. The present report was approved for publication on 22 May 1968 and has been designated as Submarine Medical Center, Submarine Medical Research Laboratory Report No. 527. This is Report No. 29 on the Work Unit listed above.

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ABSTRACT

This study determined the general performance and survival times afforded by the "Empress" polyvinylchloride exposure suit (PVCES) and the present submarine deck exposure suit in 44°F water, 32°F air, and 20 MPH wind speed. Tests were also conducted utilizing the PVCES and the SDES in 44°F water, 20°F air, 20 MPH wind — (a) one-half hour in the water, standing (Bridge simulation), (b) one hour out of the water standing (simulated Conning watch) in 20°F air, 20 MPH wind — (c) man dry, moving about the habitat. It was found that the PVCES did provide reasonable survival time at the extreme environmental condition (44°F water, 32°F air, 20 MPH wind) in all subjects. The four subjects were taken from the water after an average time of 1.8 hours of exposure. It was estimated that damage to the hands and feet would probably occur between 3.4 and 8.2 hours and death would occur between 5.4 to 16.1 hours of exposure. Wearing the SDES, the four subjects were taken from the water after an average time of 1.1 hours of exposure. It was estimated that damage to the hands and feet would probably occur between 2.0 and 4.4 hours while death would require 4.0 to 7.8 hours of exposure. Tests conducted on the PVCES simulating Bridge and Conning Tower Watch conditions, and also during the dry experiments, indicated that no discomfort would be encountered during the normal watch-standing time interval.

Figure 1 — The present submarine deck exposure suit.

THERMAL EVALUATION OF A POLYVINYLCHLORIDE EXPOSURE SUIT (EMPRESS) AND COMPARISON WITH PRESENT SUBMARINE DECK EXPOSURE SUIT

INTRODUCTION

In April 1967, two submariners, wearing the present submarine deck exposure suits shown in Figure 1, were swept overboard in 38°F water. Within minutes lines were thrown to them; however, neither man was capable of helping himself. A swimmer, who went in the water to rescue them, was paralyzed from the shock of the cold water and had to be pulled out after only four minutes in the water. This case tragically points out a serious material shortcoming within the submarine forces — the lack of adequate immersion exposure protection against cold water. The present submarine deck exposure suit is not effective protection against cold water. Although designed not to leak, nevertheless it does and the water entering the suit rapidly soaks the foul weather gear worn underneath.

The only anti-exposure protection currently available to submariners are swimmer's wet suits. However, wet suits are not the optimum solution, as they are of limited effectiveness in cold air and are not durable enough to withstand the everyday wear and tear of submarine use. Furthermore, as wet suits must be reasonably close-fitting, it would be impractical to provide a wet suit for each potential user.

The most practical solution to the submarine immersion exposure problem is a concept similar to that being designed for Naval aviators. This concept consists of a loose-fitting wet suit, shown in Figure 2, which uses polyvinylchloride (PVC) foam as the insulating material. PVC is similar to the foam neoprene used in swimmers' wet suits in that it depends upon air bubbles trapped within it for its distinctive insulating qualities. PVC is also inherently buoyant as shown in Figure 3.

The Submarine Safety Center has recently started a technical evaluation of a PVC exposure suit made by a private concern. This suit has approximately thirty pounds of positive buoyancy and a waterproof outer coating. It is lightweight and can serve as very effective foul weather equipment, a life preserver and anti-exposure suit in the event of a man overboard. Before final recommendation of this suit to the Submarine Force Commanders, the Submarine Safety Center requested that the Submarine Medical Center undertake an investigation to determine how long men could be expected to survive under various environmental conditions using the "Empress" polyvinylchloride exposure suit. The specific extreme environmental conditions encountered during routine patrol operations were used as a starting point.

Investigators from the Military Operations Branch of the Submarine Medical Center, utilizing the facilities of the Aerospace Crew Equipment Department, Philadelphia, Pennsylvania, were directed to conduct this experimentation.

BACKGROUND

Thermodynamically, the human body may be considered a core surrounded by a protective outer shell. If the difference between the core temperature and the water temperature is great enough, body heat loss is directly proportional to this difference. Cold stress occurs when large amounts of body heat are lost. McQueen[1] describes amnesia and disorientation at core temperatures below 94.2°F. These results are based on clinical experience with hypothermic anesthesia. Voluntary motion disappears at 80.6°F, and cardiac irregularities have been described when the temperature goes below 90°F[2]. In the human, the critical low temperature for consciousness is approximately 86°F. Reports indicate that the untreated, volunteer, immersion subject becomes thermolabile and tends to become poikilothermic[3] below 94°F. If crew members are to survive

Figure 2 — The polyvinylchloride exposure suit with British MK VII SEIE gloves.

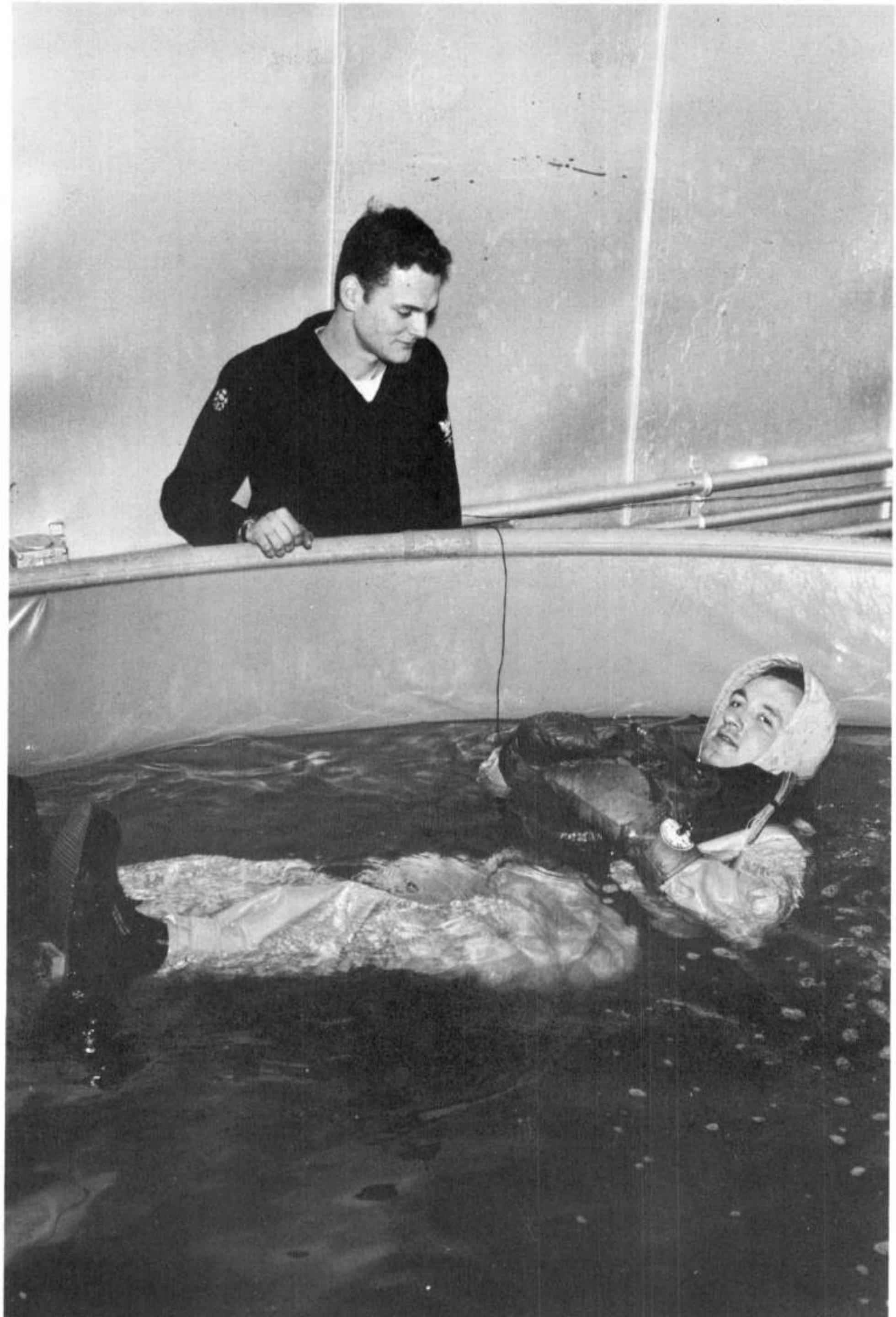


Figure 3 — Volunteer subject wearing the PVC exposure suit in 44°F water, 32°F air and a 20 MPH wind. Suit displays its inherent positive buoyancy.

and benefit from rescue operations, central temperatures should be maintained above 94°F.

For the most part, the environment controls the skin temperature of the body. Skin temperatures are higher over the trunk and lower over the extremities, usually approximating 91°F. Discomfort occurs at about 88°F[4]. A skin temperature maintained at 55°F or below may frequently result in pain and nerve damage. The rate of heat loss in the extremities is considerably higher than the trunk and head areas.

Through the processes of respiration, conduction-convection via the body shell, and by micturition and sweating, loss of body heat takes place during immersion in cold environments. In the process of respiration, inspired air is warmed, humidified, and then expired with the resultant loss of a considerable amount of heat. The amount of loss is proportional to the volume of air breathed per unit of time.

Conduction-convection transfer from the skin to the environment is another mechanism of body heat loss. The loss by this process is proportional to the temperature gradient between the skin and the surrounding medium. The insulative value of the body shell, skin and adipose tissue, the rate at which heat is conducted to the skin via the underlying vascular system, and the thermal capacity and conductivity of the environment, control the rate of heat transfer. Vasoconstriction of the vessels of the "shell" tissues, which function as a heat exchange, and the thickness of the skin and adipose tissue control the rate of heat loss. The thermoconductivity of the skin varies with the degree of vasoconstriction.

Immersion in cold water increases urine output to a significant degree under certain conditions. Experiments conducted by Beckman[3] et al have shown that the urinary volume may be increased to 1-3 liters in 3 hours due to immersion and chilling. Excretion of 2 liters of urine by a diver in 50°F water could lower the mean body temperature by 1.8°F.

The balance of the heat loss from the body and the heat gained from metabolism within the body determines the body temperature. Since the rates of heat loss and heat gain may be of large magnitude, the body temperature is a delicate and sensitive indicator of the state of thermal balance.

Behnke and Yaglou[5] showed that, when a group of nude men entered 43°F water, excruciating pains all over the body were experienced. This was the period of vasoconstriction, when skin temperatures were falling and core temperature was rising. As skin temperatures approximated the water temperature, the pain subsided and central temperature began to fall. Cyanosis and shivering were observed very early and the shivering progressed to a state of violent shaking. In addition to the pain, it is known that as core temperature decreases, there is progressive deterioration and impairment of higher mental processes. At 90°F a condition of stupor exists and unconsciousness occurs in most individuals below 86°F. Drowning becomes a significant problem in cold immersion situations because of less discriminating sensory perception and motor function.

If drowning is prevented by the support of life vests, the effects of immersion hypothermia on cardiac rhythm occurs. Angelakos[6] has shown that, in dogs, anesthetized with pentobarbital, ventricular fibrillation was the predominant mode of death at temperatures of 75 to 68°F, while cardiac arrest accounted principally for mortality at lower temperatures — about 62 to 59°F.

Death may occur after removal from frigid water. This "rewarming shock" has been a commonly-observed phenomenon, and together with electrolyte alterations or irreversible renal, endocrinologic, or other damage, can produce death even after rescue. When possible, a man should be rewarmed in 108 to 112°F water, but great care should be taken never to have the water warmer than 112°F.[7]

Critchley[8] describes the loss of will to live, as the "spiritual failure" and lists it as the cause of 20% of the deaths among immersed personnel. Beckman and Reeves[9] describe the fact that one or two cases of "spiritual failure" in their tests were actually suffering from hypoglycemia. Further, 5 of the 24 subjects (21%) had measurable hypoglycemia, this suggests that hypoglycemia may be the major physiological factor in the so-called "spiritual failure" of shipwrecked survivors.

METHODS AND MATERIALS

Four enlisted submariners were subjects for this project. The physical measurements of the four subjects are listed in Table I*. Each subject was notified 24 hours before his participation and instructed to:

1. Abstain from alcoholic beverages for 12 hours before the experiment.
2. Obtain a normal night's sleep; and
3. Eat a well-balanced breakfast prior to reporting to the laboratory.

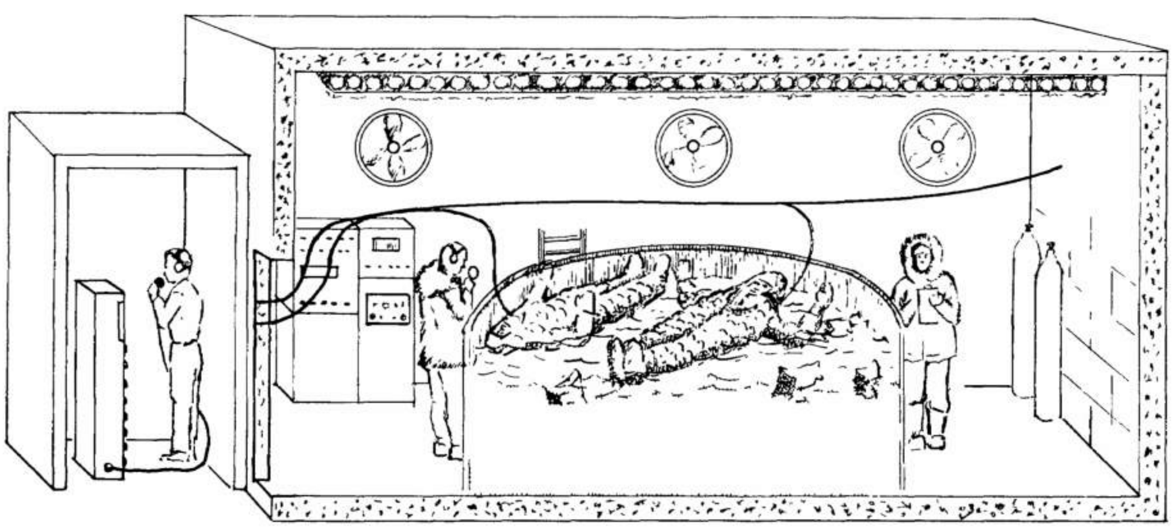
No food or water was taken by the subjects during the experiments.

Multipoint surface temperatures were monitored using 15 thermistors. The locations are shown in Table II. Core temperatures were measured, employing a rectal thermistor probe, and a single-lead electrocardiogram was monitored continuously.

Baseline laboratory studies and physical examinations were performed on each subject. A general physical examination, specific anthropomorphic measurements, ECG, CBC, cholesterol, and urinalysis were performed. All laboratory studies were within normal limits. Table III provides anthropomorphic measurements.

The environmental laboratory (Figure 4) was 24 x 24 x 15 feet and contained a pool 18 feet in diameter and 4 feet deep. The following ranges were possible within this laboratory:

1. Air temperature 10°F to 85°F;
2. Water temperature 29°F to 90°F; and



Environmental Laboratory and Pool

Figure 4 — The following conditions could be attained in the environmental laboratory and pool — air temperature 10° to 85°F.; water temperature 29° to 90°F.; and wind velocity from 0-20 MPH.

* All tables appear at end of report, beginning on Page 14.

3. Wind velocity 0-20 miles per hour.

Two subjects were tested at a time. All four subjects were exposed to each set of environmental conditions. Each subject completed a pre-trial questionnaire (Figure 5); then voided and was weighed nude; the volume and specific gravity of the urine was recorded (Table IV); thermistors and ECG leads were attached; and the subjects were dressed in their underwear, dungarees, and a sweater under the Empress suit, or complete standard foul weather gear under the present deck exposure suit. The PVCES or the SDES was donned and thermistor and ECG lead continuity was confirmed. Standard Mark VI thermal boots and British Mark VII gloves were worn with the PVCES. The subjects entered the water and were free to move about the pool (Figure 6). One hospital-corpsman closely observed each subject. Continuous ECG and temperature measurements were monitored (Figure 7). Subjective comments were elicited from the volunteers and recorded periodically (Figure 8).

At the termination of a test, the subject moved to an adjacent rewarming area (Figure 9.) The room contained a pool of water heated to 110°F. When the condition of the subject was deemed satisfactory, the subject undressed, voided and was re-weighed. A post-exposure medical examination was made, and post-trial questionnaire completed Figure 10). The subjects were then released to their corpsmen.

The four subjects were exposed to the conditions shown in Table V, until one of the following limitations occurred:

1. Unfavorable subjective response.
2. Rectal temperature 95°F or 103°F.
3. Skin surface temperatures lowered to unacceptable limits (46°F).
4. Cardiac arrythmias.

All testing was terminated after six hours, if the above conditions had not caused earlier termination.

Motivation plays a very important role in survival at sea, particularly in cold water. Therefore, it was decided to maintain morale as high as possible in all subjects under all conditions by motivation stimulation through exercise and general harrassment.

FIGURE 5

PRE-IMMERSION QUESTIONNAIRE
(To cover preceding 24 hours before immersion)

SUBJECT NO. ____________

(a) Food Eaten: Dinner.
Snack
Supper
Breakfast.

(b) Estimation of Fluids Taken:
Breakfast
Mid-morning coffee
Dinner
Afternoon coffee
Supper
Late night
Early morning
Beer - morning Wines/spirits
evening
Other fluids

(c) Activities prior to immersion:
Sports or other strenuous activity
Time spent

(d) Other information:

Signature ______________________

Figure 5—Pre-Immersion Questionnaire.

RESULTS

Polyvinylchloride exposure suit experiments:

A. 44°F water, 32°F air, 20 MPH wind.

All four subjects sustained 1.5 hours or more of exposure before the experiment was terminated. In most cases objective extremity temperature data forced termination of the run. The following exposure times were attained:

Figure 6—Volunteer test subjects wearing the (a) submarine deck exposure suit and (b) polyvinylchloride exposure suit.

Figure 7—Rt. Automatic Temperature Monitoring System. Left—"Max" cart—mobile intensive care and emergency life support system.

SUBJECT	D	H	C	L
Time (Hours)	2.0	1.8	2.0	1.5

Four temperature areas showed a significant decrease in all experiments and these areas together with mean weighted skin temperatures (MWST) and mean body temperature (MBT) are shown in Tables VI-IX and represented in Figures 11-14.

AREA	TIME
HEAD	
FACE	
NECK	
SHOULDER	
BACK	
UPPER ARM	
LOWER ARM	
HAND	
FINGERS	
PELVIC AREA	
GROIN	
THIGHS	
LOWER LEG	
FEET	
TOES	
DEFECATION	
URINATION	
SUIT LEAKS	
LEAK LOCATION	
SUBJECT FEELINGS	

Figure 8—Escape and Exposure Suit Evaluation; Subject Observation Chronology.

Figure 9—Subject being rewarmed after an experiment, with observers and physician present.

B. 44°F water, 20°F air, 20 MPH wind.

(½ hour in the water, standing; 1 hour out, standing.)

All four subjects completed at least 3 hours of exposure before the experiment was terminated. Three subjects were taken from the water because of low extremity temperature. The fourth man completed the time limit of 6 hours. The following exposure times were attained:

SUBJECT	**D**	**H**	**C**	**L**
Time (Hours)	6.0	3.2	3.5	3.0

The same four temperature areas showed a decrease in all experiments and these values are shown in Tables X-XIII together with the MWST and MBT. This tabular information is represented in Figures 15-18.

C. 20°F air, 20 MPH wind.

(Man dry moving about the habitat.)

All four subjects completed the time limit, 6 hours of exposure. Four temperature areas showed a significant decrease in all experiments and these areas together with the MWST and MBT are shown in Tables XIV-XVII and represented in Figures 19-22.

Present submarine deck exposure suit: (SDES):

A. 44°F water, 32°F air, 20 MPH wind.

All four subjects sustained 0.5 hours of exposure or more before the experiment was terminated. In all cases objective extremity temperature data forced termination of the run. The following exposures were attained:

SUBJECT	**D**	**H**	**C**	**L**
Time (Hours)	1.5	1.5	0.9	0.5

Four temperature areas showed a significant decrease in all experiments and these areas together with the MWST and MBT are shown in Tables XVIII-XXI and represented in Figures 23-26.

Subjective comments collected during the course of the project noted the following:

A. **PVCES:**

1. Upon entering the water, both wrist and ankle cuffs admitted water which usually pooled in the low back area.

POST-RUN QUESTIONNAIRE

SUBJECT NO ________

1 SUIT

(a) Did you have any difficulty in putting the suit on?

(b) While waiting for the run to start, did you experience any discomfort and were you sweating?

(c) Did you have any discomfort in the water before you inflated the suit?

(d) Did you have any difficulty in inflating the suit?

(e) Did you have any difficulty in removing the mitts from their stowage and/or in putting them on?

(f) Were you comfortable once the suit was inflated?

(g) Did the suit require readjustment, if so, how often?

(h) Did the suit leak?

2 PERSONAL

(a) Did you pass any urine during the time you were in the water, if so, how many times?

(b) Was there any difficulty in passing urine?

(c) Have you any comments to make on the effectiveness of the suit?

(d) What, if any, complaints do you have regarding personal comfort or distress?

Signature________________

Figure 10—Post-Run Questionnaire.

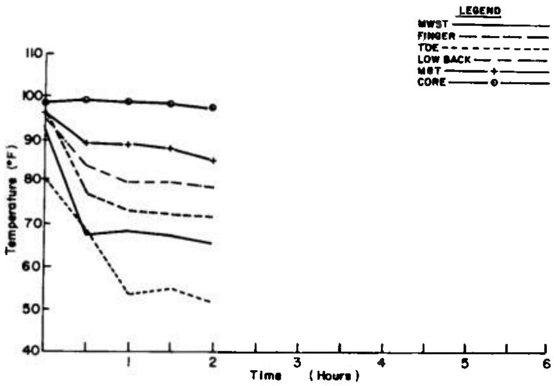


Figure 11—Motivated Subject D exposed to 44°F water, 32°F air, 20 MPH wind.

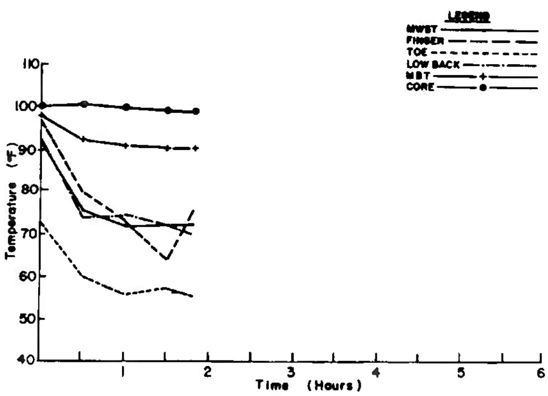


Figure 12—Motivated Subject H exposed to 44°F water, 32°F air, 20 MPH wind.

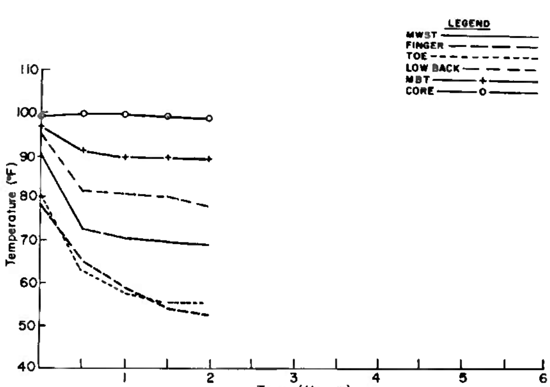


Figure 13—Motivated Subject C exposed to 44°F water, 32°F air, 20 MPH wind.

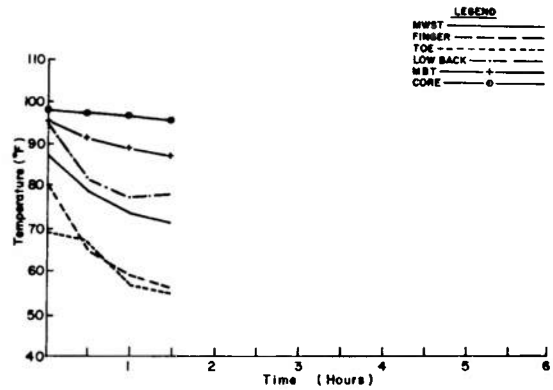


Figure 14—Motivated Subject L exposed to 44°F water, 32°F air, 20 MPH wind.

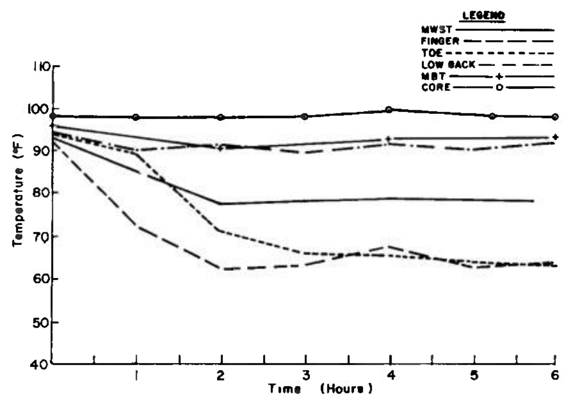


Figure 15—Motivated Subject D exposed to 44°F water, 20°F air, 20 MPH wind. (½ hour in the water, standing; 1 hour out, standing)

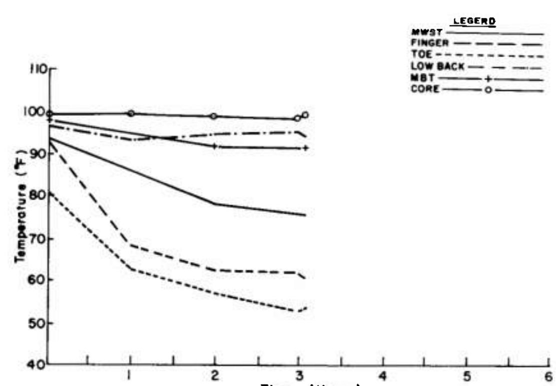


Figure 16—Motivated Subject H exposed to 44°F water, 20°F air, 20 MPH wind. (½ hour in the water, standing; 1 hour out, standing)

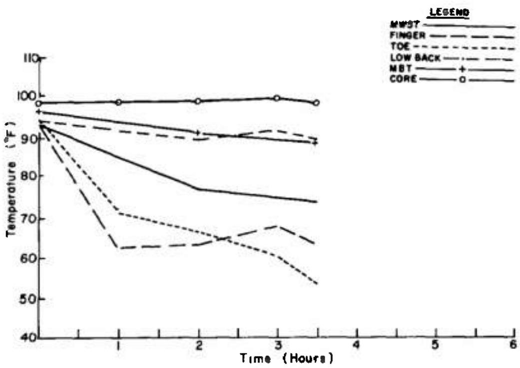


Figure 17—Motivated Subject C exposed to 44°F water, 20°F air, 20 MPH wind. (½ hour in the water, standing; 1 hour out, standing)

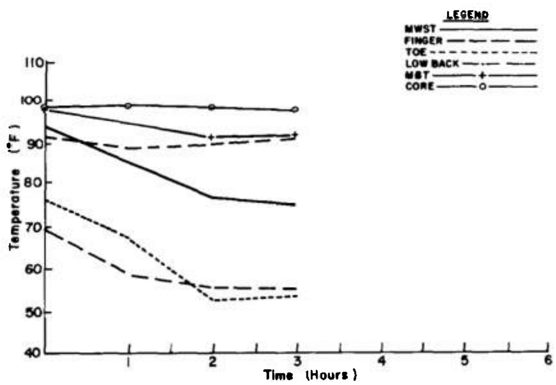


Figure 18—Motivated Subject L exposed to 44°F water, 20°F air, 20 MPH wind. (½ hour in the water, standing; 1 hour out, standing)

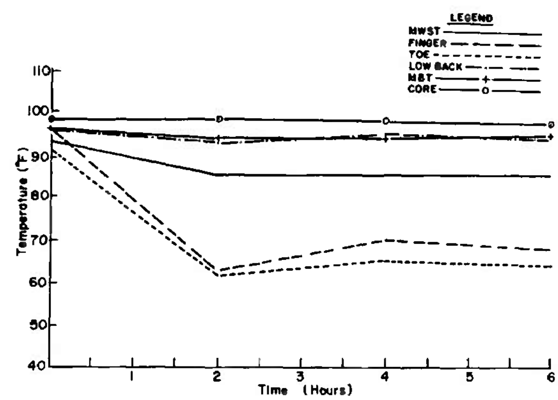


Figure 19—Motivated Subject D exposed to 20°F air, 20 MPH wind (man dry moving about the habitat).

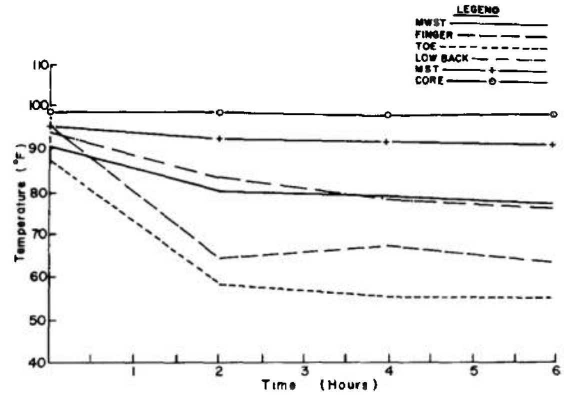


Figure 20—Motivated Subject H exposed to 20°F air, 20 MPH wind (man dry moving about the habitat).

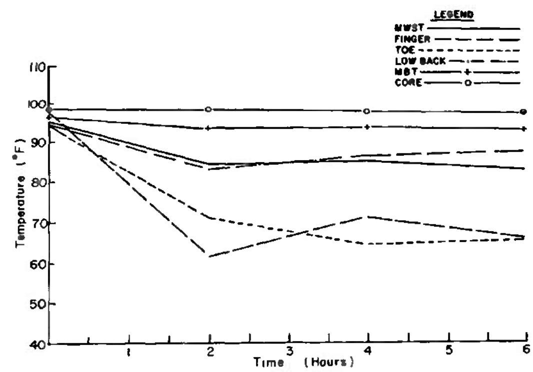


Figure 21—Motivated Subject C exposed to 20°F air, 20 MPH wind (man dry moving about the habitat).

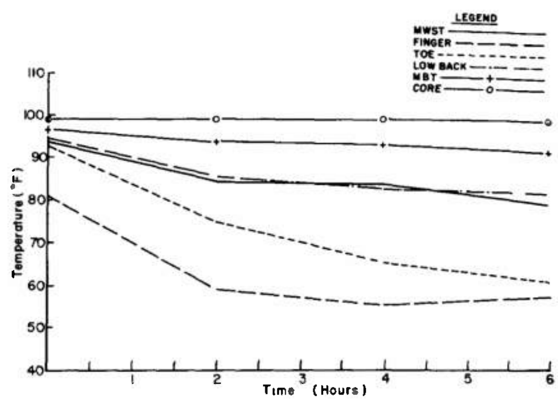


Figure 22—Motivated Subject L exposed to 20°F air, 20 MPH wind (man dry moving about the habitat).

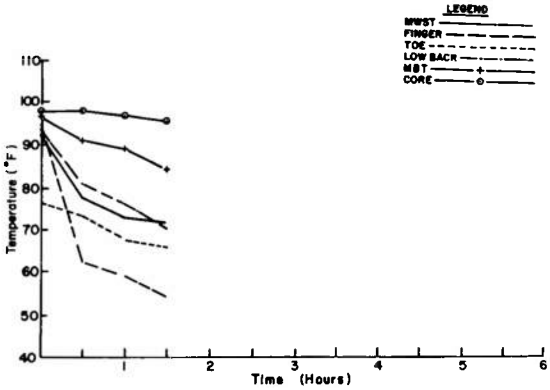


Figure 23—Motivated Subject D exposed to 44°F water, 32°F air, 20 MPH wind.

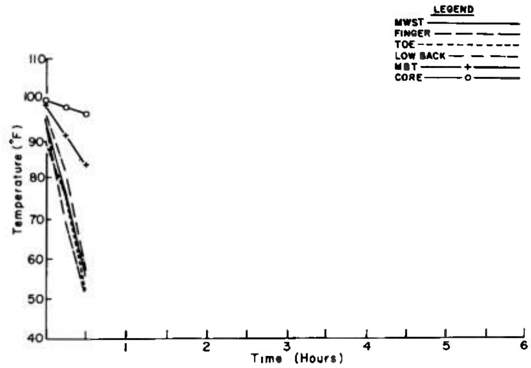


Figure 26—Motivated Subject L exposed to 44°F water, 32°F air, 20 MPH wind.

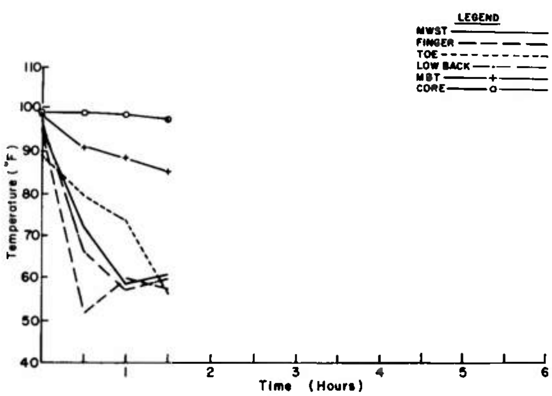


Figure 24—Motivated Subject H exposed to 44°F water, 32°F air, 20 MPH wind.

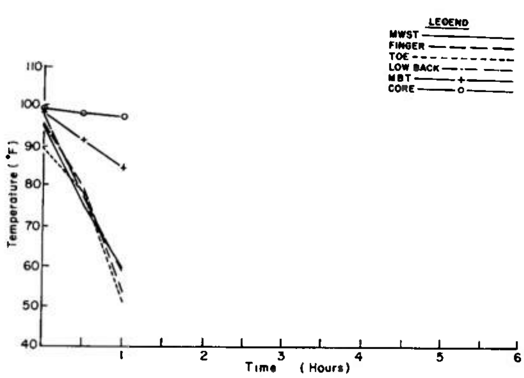


Figure 25—Motivated Subject C exposed to 44°F water, 32°F air, 20 MPH wind.

2. The glove-suit interface was inadequate. This permitted water to enter at the wrists.

3. Once the water entered the suit, it appeared to remain. All subjects reported some warming trends after initial immersion.

4. The neck area contributed somewhat to water entry.

5. As time progressed after the initial entry into the water, the suit appeared to lose part of its buoyancy. This apparently is due to the loss of the air that is trapped within the suit layers.

6. All subjects reported the suit as comfortable and quite workable.

B. SDES:

1. The suit admitted water from all areas (cuffs and neck) immediately upon entry into the water. The neck area was particularly prone to this fault.

2. Water moved freely through the suit and made rewarming of it impossible. Any movement at all greatly increased this process.

3. The suit was very difficult to don and working movements or life-saving movements would be impossible.

4. The subjects did not have one favorable statement about this suit.

DISCUSSION

The primary purpose of this experimentation was to determine the performance and survival time provided by the "Empress" polyvinylchloride exposure suit (PVCES) and the present submarine deck exposure suit (SDES) under specific environmental conditions.

A six-hour limit was placed on exposure times because of the following restrictions:

1. The same subjects participated in all experiments.

2. The subjects occasionally participated in two trials within a single week.

3. The subjects who volunteered to participate performed their normal shipboard duties as well.

4. A six-hour exposure would provide reasonable information from which extrapolation to theoretical end-points could be made.

The critical question to be answered was, at what point in time will permanent damage occur to extremities and when will death supervene? The most sensitive tissue in each man under each condition was chosen as the limiting tissue. Permanent tissue damage would be expected with approximately one hour exposure at 40°F.

The decrease in core temperature for each condition was calculated and extrapolated to 86°F, the theoretical end-point or death. It is at this temperature that most individuals become unconscious, may drown, and in many cases display cardiac irregularities[2].

Estimating the exposure times, which would produce permanent tissue damage, was accomplished by calculating the rate of temperature change during the late, stable portion of the temperature curve. Extrapolation of the time-temperature curve to a point of 40°F plus an additional exposure of one hour at this temperature provides the projected end-point.

Survival times were calculated from the rate of core temperature change. Using the value from the highest core temperature reading to the value at the termination of the experiment, extrapolation to the predetermined end-point of 86°F was made. Because this rate of change usually increases at temperatures below 95°F, valid end-points are difficult to project. Table XXII shows the results of these calculations and the termination times for each experiment under each condition.

The experimental data indicates that additional exposure protection was provided by the polyvinylchloride exposure suit versus the present submarine deck exposure suit. The inherent buoyancy offered by this suit adds to its desirability. The working mobility and rapid donning qualities of the PVCES are favorable. The suit appears to be durable and possibly only one size suit would be necessary to fit most of the crew.

The glove-suit and boot-suit interfaces were inadequate. Water consistently penetrated these areas. This naturally detracted from the exposure time. Objective temperature measurements in the lower extremities, particularly the large toe, caused early termination of many tests. Pain and cold in the back area were noted.

The exposure times indicate that a man or group of men could survive long enough so that rescue from a "man overboard" situation would be possible.

CONCLUSIONS

1. The polyvinylchloride exposure suit (PVCES) would probably eliminate the immediate exposure casualties that might be expected from men entering cold water.

2. The PVCES did provide reasonable survival time at the extreme environmental condition (44°F water, 32°F air, 20 MPH wind) which was specifically desired.

3. The experimental data indicates that increased exposure protection was provided by the polyvinylchloride suit versus the present submarine deck exposure suit, (SDES).

4. Considering the rates of temperature change over the times observed, the extremities of the most sensitive men would probably be damaged after about:

   A. Polyvinylchloride Exposure Suit:

      (1) 3.4 hours at 44°F water, 32°F air, 20 MPH wind.

      (2) 6.6 hours at 44°F water, 20°F air, 20 MPH wind.
         (½ hour in the water) — Bridge
         (1 hour out of the water)— Conning Tower

      (3) >8 hours at 20°F air, 20 MPH wind.
         (man dry, no immersion)

   B. Present Submarine Deck Exposure Suit:

      (1) 1.6 hours at 44°F water, 32°F air, 20 MPH wind.

5. The critical core temperature (86°F) would occur in the most sensitive men after about:

   A. Polyvinylchloride Exposure Suit:

      (1) 5.4 hours at 44°F water, 32°F air, 20 MPH wind.

   B. Present Submarine Deck Exposure Suit:

      (1) 1.9 hours at 44°F water, 32°F air, 20 MPH wind.

6. The inherent buoyancy offered by the PVCES together with the mobility and rapid donning qualities make it far superior to the present suit.

7. The exposure times of the men wearing Polyvinylchloride Exposure Suit indicate that rescue and survival would be enhanced during a "man overboard" situation if this suit were employed.

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TABLE I

PHYSICAL CHARACTERISTICS OF EXPERIMENTAL SUBJECTS

SUBJECT	AGE	HEIGHT (cm)	WEIGHT (kg)	SURFACE AREA (M^2)	%BODY FAT	SPEC. GRAV.
D	27	170.5	82.5	1.92	14.9	1.07
H	29	168.5	75.0	1.82	14.9	1.07
C	23	178.5	76.0	1.91	13.4	1.07
L	20	173.4	67.0	1.77	13.0	1.08
AVERAGE	24.8	172.8	75.1	1.85	14.0	1.07

TABLE II

THERMISTOR POSITIONS

POSITION
Rectal
Right big toe, bottom
Right foot, dorsum
Right calf, lateral
Right mid-thigh, lateral
Right mid-thigh, medial
Xiphoid
Right upper chest
Right scapula
Low back
Right index finger, pad
Right hand, dorsum
Right forearm
Right arm, deltoid area
Forehead

TABLE III

ANTHROPOMORPHIC MEASUREMENTS
(Kg., Cm.)

		SUBJECTS			
		D	H	C	L
1.	Weight (kg.)	82.5	75.0	76.0	67.0
2.	Stature	170.5	168.5	178.5	173.4
3.	Acromial Ht.	138.1	137.1	145.4	141.6
4.	Radial Ht. (Elbow)	107.1	106.5	111.4	107.2
5.	Stylion Ht. (Wrist)	85.7	80.0	87.7	86.4
6.	Dactylion Ht. (Fingertip)	63.6	61.5	66.7	68.4
7.	Trochanteric Ht. (Waist)	96.9	97.3	107.0	100.7
8.	Gluteal Furrow Ht.	76.5	79.6	85.4	81.7
9.	Chest Depth	24.7	25.7	23.3	22.3
10.	Chest Breadth	37.6	32.5	31.0	30.6
11.	Wrist Thickness	5.8	5.7	5.7	5.6
12.	Elbow Thickness	6.8	6.7	6.9	6.3
13.	Knee Thickness	10.3	9.3	11.0	10.1
14.	Ankle Thickness	7.5	6.2	7.6	7.2
15.	Foot Length	26.9	26.0	26.3	24.4
16.	Foot Breadth	10.4	8.6	9.0	9.5
17.	Chest Circ.	110.3	95.9	93.3	88.2
18.	Waist Circ.	91.2	91.1	86.8	81.8
19.	Hip Circ.	99.7	96.8	98.4	88.6
20.	Triceps Skinfold	0.9	0.9	0.7	0.5
21.	Subscapular Skinfold	1.2	1.2	0.9	1.0
22.	Sitting Ht.	90.4	85.6	90.2	87.4
23.	Buttock Knee Lgth.	59.2	59.2	62.9	61.7
24.	Hand Lgth.	19.1	18.6	18.9	17.1
25.	Hand Breadth	8.5	8.0	7.5	8.1
26.	Head Lgth.	19.2	19.4	17.9	18.1
27.	Head Breadth	16.5	15.0	15.2	15.3
28.	Diacromial Breadth	47.1	43.5	45.3	43.2
29.	Age (Years)	27	29	23	20

TABLE IV

SUMMARY OF PRE, POST WEIGHT AND URINE SPECIFIC GRAVITY DATA

ENVIRONMENTAL CONDITION	SUBJECT	WEIGHT		URINE SPECIFIC GRAVITY	
		PRE	POST	PRE	POST
A. 44, 32, 20	D	181	179	1.010	1.008
	H	161	160	1.010	1.011
	C	181	180	1.030	1.010
	L	144	143	1.010	1.010
B. 44, 20, 20	D	180	179	1.015	1.010
	H	160	159	1.025	1.015
	C	185	183	1.010	1.010
	L	143	142	1.026	1.028
C. 20, 20	D	177	177	1.010	1.019
	H	161	159	1.015	1.010
	C	185	183	1.010	1.010
	L	143	142	1.026	1.028
D. 44, 32, 20 *	D	178	177	1.010	1.008
	H	162	158	1.015	1.017
	C	183	183	1.025	1.030
	L	144	143	1.021	1.020

*Present Submarine Deck Exposure Suit

(a) All other experiments with the PVCES.

TABLE V

SUMMARY OF ENVIRONMENTAL CONDITIONS

WATER TEMPERATURE (F^o)		AIR TEMPERATURE (F^o)	WIND VELOCITY MPH
1*	44	32	20
2#	44	20	20
3¢	--	20	20

*2 experiments (4 men each); (1) PVCES; (2) SDES.
#1 experiment (PVCES); (1) ½ hour in the water, standing (Bridge simulation; (2) 1 hour out of the water (Conning watch).
¢1 experiment (PVCES); (1) men dry moving about the habitat.

TABLES VI-IX

44°F WATER, 32°F AIR, 20 MPH WIND
(POLYVINYLCHLORIDE EXPOSURE SUIT)

TABLE VI

SUBJECT D

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	985	812	957	971	933	967
0.5	992	685	835	768	682	887
1.0	985	531	796	729	681	882
1.5	980	545	794	722	670	876
2.0	972	510	782	716	654	848

TABLE VII

SUBJECT H

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	998	726	918	967	919	971
0.5	1001	597	734	797	756	918
1.0	998	560	740	733	716	903
1.5	990	574	720	633	719	899
1.8	989	555	699	754	722	898

TABLE VIII

SUBJECT C

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	992	812	955	788	908	963
0.5	999	626	817	650	730	908
1.0	997	573	808	585	704	898
1.5	992	557	800	536	698	893
2.0	987	553	776	524	684	885

TABLE IX

SUBJECT L

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	985	699	951	810	883	950
0.5	976	675	819	650	799	919
1.0	970	567	775	590	741	893
1.5	954	549	783	552	711	872

TABLES X-XIII

44°F WATER, 20°F AIR, 20 MPH WIND
(POLYVINYLCHLORIDE EXPOSURE SUIT)

TABLE X

SUBJECT D

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	985	948	942	928	931	966
1	983	898	904	721		
2	983	709	917	626	771	911
3	985	659	897	633		
4	998	651	916	676	784	926
5	981	643	901	634		
6	980	629	920	635	780	924

TABLE XI

SUBJECT H

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	999	812	968	929	936	977
1	995	629	933	683		
2	990	573	948	625	781	919
3	986	529	952	621		
3.2	991	538	935	604	759	913

TABLE XII

SUBJECT C

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	984	947	943	927	930	965
1	983	710	918	627		
2	984	660	898	634	769	909
3	997	600	915	676		
3.5	981	532	899	635	741	889

TABLE XIII

SUBJECT L

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	984	766	911	696	934	976
1	991	637	873	586		
2	985	528	894	556	762	916
3	979	535	901	555	754	911

TABLES XIV-XVII

$20^{o}F$ AIR, 20 MPH WIND
(POLYVINYLCHLORIDE EXPOSURE SUIT)

SUBJECT D

TABLE XIV

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	981	913	957	964	933	964
2	982	615	928	621	850	937
4	980	652	951	701	855	937
6	978	644	935	683	854	936

SUBJECT H

TABLE XV

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	994	877	949	966	913	966
2	990	583	832	646	809	929
4	988	555	780	679	798	924
6	985	553	762	635	777	915

SUBJECT C

TABLE XVI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	986	970	946	984	952	974
2	984	711	833	615	830	932
4	981	642	867	717	850	936
6	979	653	877	652	829	928

SUBJECT L

TABLE XVII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	984	925	946	812	940	968
2	983	753	853	591	840	934
4	981	653	825	554	827	929
6	980	611	810	570	796	918

TABLES XVIII-XXI

$44^{\circ}F$ WATER, $32^{\circ}F$ AIR, 20 MPH WIND
(PRESENT SUBMARINE DECK EXPOSURE SUIT)

SUBJECT D

TABLE XVIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	982	767	949	959	930	964
0.5	983	731	809	621	785	916
1.0	971	678	767	599	730	890
1.5	958	660	706	546	724	848

SUBJECT H

TABLE XIX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	997	895	976	958	953	981
0.5	992	799	606	518	722	901
1.0	981	736	574	600	581	880
1.5	973	566	595	571	608	850

SUBJECT C

TABLE XX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	992	894	975	958	951	980
0.5	981	783	773	786	762	913
0.9	974	512	587	532	592	845

SUBJECT L

TABLE XXI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	996	897	965	949	953	983
0.25	980	750	811	698	751	902
0.5	961	522	572	505	574	837

TABLE XXII

SUMMARY OF EXPOSURE TIMES OF MEN WEARING THE "EMPRESS" POLYVINYLCHLORIDE EXPOSURE SUIT AND THE PRESENT SUBMARINE DECK EXPOSURE SUIT NECESSARY TO PRODUCE TERMINATION OF THE EXPERIMENT, TISSUE DAMAGE AND DEATH AT THE VARIOUS ENVIRONMENTAL CONDITIONS.

Environmental Condition	(1) Termination of Experiment. (2) Tissue Damage. (3) Death	Subject Time (hours)				Range (hours)
		D	H	C	L	
A. 44, 32, 20 (PVCES)	(1)	2.0	1.8	2.0	1.5	(1.5-2.0)
	(2)	8.2	6.5	5.0	3.4	(3.4-8.2)
	(3)	10.6	16.1	14.7	5.4	(5.4-16.1)
B. 44, 20, 20 (PVCES) ½ hour in water 1 hour out	(1)	6.0	3.2	3.5	3.0	(3.0-6.0)
	(2)	18.5	7.6	6.6	8.0	(6.6-18.5)
C. 20, 20 (PVCES) Man dry	(1)	6.0	6.0	6.0	6.0	(6.0)
D. 44, 32, 20 (SDES)	(1)	1.5	1.5	0.9	0.5	(.5-1.5)
	(2)	4.4	3.2	2.1	1.6	(1.6-4.4)
	(3)	5.6	7.8	6.6	1.9	(1.9-7.8)

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13 ABSTRACT

This study determined the general performance and survival times afforded by the "Empress" polyvinylchloride exposure suit (PVES) and the present submarine deck exposure suit in 44°F. water, 32°F. air, and 20 MPH wind speed. Tests were also conducted utilizing the PVCES in 44°F. water, 20°F. air, and 20 MPH wind, with: (a) men standing one-half hour in the water (simulating Bridge watch); (b) men standing one hour, out of the water, in 20°F. air, 20 MPH wind (simulating Conning Tower watch); men dry, moving about the habitat.

It was found that the PVCES did provide reasonable survival time at the extreme environmental condition (44°F. water, 32°F. air, 20 MPH wind) in all subjects, and that the four subjects were taken from the water after an average time of 1.8 hours of exposure. It was estimated that damage to the hands and feet would probably occur between 3.4 and 8.2 hours and death would probably occur between 5.4 and 16.1 hours of exposure. Wearing the SDES, the four subjects were taken from the water after an average time of 1.1 hours of exposure. It was estimated that damage to the hands and feet would probably occur between 2.0 and 4.4 hours, while death would require 4.0 to 7.8 hours of exposure. Tests conducted on the PVCES simulating Bridge and Conning Tower watch conditions and also during the dry experiments indicated that no discomfort would be encountered during the normal watch-standing time interval.

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Submarine protective clothing						
Rescue aid for submarine personnel						